REMARKS

Status of the Claims

Claims 1, 2, and 5-19 are pending, with claim 1 being independent. Claim 1 has been amended to even more clearly recite and distinctly claim particularly preferred embodiments of the present invention. Support for the amendment can be found throughout the specification, including, for example, at page 8, lines 9 – 13; page 9, lines 7 – 15; and page 18, lines 7 – 14. Further in support of conventional filtering meaning pressure filtering, Applicants attach hereto a copy of Chase, George G. and Ernest Mayer, "Filtration, 13. Batch Pressure Filters" Kirk-Othmer Encyclopedia of Chemical Technology, John Wiley & Sons, Inc. Accordingly, Applicants respectfully submit that no new matter has been added

Applicants respectfully request the Examiner to reconsider and withdraw the outstanding rejections in view of the foregoing amendment and the following remarks.

Presently Claimed Invention

The presently claimed invention relates to a method of removing contamination from a Fischer-Tropsch derived hydrocarbon stream. The presently claimed method comprises a) ***filtering*** a Fischer-Tropsch derived hydrocarbon stream ***with a conventional pressure filter*** to remove ***contamination having an average size greater than or equal to about 1 micron*** to produce a filtered hydrocarbon stream; b) passing ***the filtered hydrocarbon stream*** to at least one ***distillation step*** to remove contamination present as soluble species or as ultra-fine particulate from the filtered hydrocarbon stream, the distillation step producing a distillate product stream and a bottoms fraction, wherein the contamination is substantially concentrated in the bottoms fraction; and c) recovering the bottoms fraction from the distillation step, wherein the amount of the bottoms fraction is less than about 35 percent by volume of the filtered hydrocarbon stream. As disclosed in the specification, ultra-fine particulate are particles less than about 0.1 microns in size. (page 8, lines 9-11).

It has been discovered that ***conventional pressure filtering in combination with*** distillation can substantially reduce plugging of a hydroprocessing reactor. As such, the present specification discloses that the distillation step following the conventional pressure filtration can substantially reduce plugging of a hydroprocessing reactor by removing contamination present as a soluble species or as ultra-fine particulate (meaning less than

about 0.1 microns in size) since this contamination is not removed by conventional filtering. (page 8, lines 9-17).

Claim Rejections Under 35 U.S.C. § 103

Claims 1, 2, and 5-19 stand rejected under 35 U.S.C. § 103(a) as allegedly being unpatentable over U.S. Patent No. 4,605,678 ("Brennan") in view of U.S. Patent No. 6,635,682 ("Ketley"), U.S. Patent No. 2,852,546 ("Kolling"). Applicants respectfully disagree with the rejection; therefore, this rejection is respectfully traversed.

Brennan discloses a process for removing catalyst fines from the wax product produced in a slurry Fischer-Tropsch reactor comprising removing the wax product from the reactor and separating catalyst fines from the product by ***passing the wax product through a high gradient magnetic field***. The catalyst fines are held by a ***magnetized filter element*** and the wax product passes through unhindered to form a purified wax product which is ready for upgrading. (Abstract). Brennan discloses that the wax product withdrawn from a slurry reactor contains catalyst fines entrained therein which need to be removed prior to upgrading the wax product. (Col. 8, line 67-Col. 9, line 2). Brennan further discloses that a portion of the catalyst fines are smaller than 1 micron in size, such that ordinary filtration is ineffective for their removal. (Col. 9, lines 2-6). To address this problem, Brennan discloses an improved process for removal of ***substantially all*** of these small catalyst fines comprising ***high gradient magnetic separation,*** and states that the disclosed separation system is remarkably efficient in removing these small catalyst particles. (Col. 10, lines 6-22 and lines 28-31).

Accordingly, Brennan discloses a process for removing particles smaller than 1 micron in size, which *ordinary filtration is ineffective in removing*, by passing the wax product through a high gradient magnetic field. As such, Brennan does not disclose or suggest removal of contamination present as soluble species or as ultra-fine particulate (i.e., having an average size less than about 0.1 micron) by passing a filtered hydrocarbon stream to at least one distillation step. Moreover, Brennan does not disclose or suggest a method of removing contamination from a Fischer Tropsch derived hydrocarbon stream comprising filtering with a conventional pressure filter and then passing the filtered stream to at least one distillation step to remove further contamination.

Ketley discloses a process for the conversion of synthesis gas into higher hydrocarbon products in a system comprising a high shear mixing zone and a post mixing zone. (Abstract). Ketley discloses that "a portion of the suspension is withdrawn from the system and by a suitable separation means, e.g. a hydrocyclone, filter, gravity separator or magnetic separator, or alternatively, by distillation, the liquid medium and liquid hydrocarbon products may be separated from the suspended catalyst." (Col. 9, lines 5-14). Ketley lists all of the disclosed separation techniques as ***interchangeable*** without making any distinction among the various separation techniques. Accordingly, Ketley discloses that all of these separation techniques are equivalent and does not suggest the preference of one over the others. Moreover, Ketley does not disclose or suggest the problem of removal of catalysts particles of varying different sizes or removal of catalyst particles smaller than 1 micron in size, which ordinary filtration is ineffective in removing,

Kolling discloses a process for converting hard paraffins into paraffins preferably melting between about 40 and 80°C. (Col. 2, lines 7-9). As disclosed in the present specification, Kolling describes an atmospheric distillation followed by a vacuum distillation of a Fischer-Tropsch wax to separate paraffins with melting points between 40 and 80°C. (page 16, line 31 – page 17, line 2). Accordingly, Kolling discloses an atmospheric distillation followed by a vacuum distillation as a ***separation technique to provide desired Fischer-Tropsch products***, not to remove contamination.

To establish a *prima facie* case of obviousness, three basic criteria must be met. First, there must be some suggestion or motivation, either in the references themselves or in the knowledge generally available to one of ordinary skill in the art, to combine the reference teachings. Second, there must be a reasonable expectation of success. Finally, the prior art reference (or references when combined) must teach or suggest all the claim limitations. MPEP § 2143.

It is respectfully submitted that even if there were some suggestion or motivation to combine Brennan with Ketley and/or Kolling and a reasonable expectation of success, even if combined Brennan and Ketley and/or Kolling do not disclose or suggest all of the claim limitations of the presently claimed method for removing contamination from a Fischer-Tropsch derived hydrocarbon stream.

As described above, Brennan discloses a process for removing particles smaller than 1 micron in size, which ordinary filtration is ineffective in removing, by passing the wax

product through a ***high gradient magnetic field***. Also as described above, Ketley provides that the suspension withdrawn from the disclosed system is subjected to a suitable separation means, e.g. a hydrocyclone, filter, gravity separator or magnetic separator, or alternatively, by distillation, without making any distinction or providing any basis on which to select among the various separation techniques. Kolling discloses an atmospheric distillation followed by a vacuum distillation as a ***separation technique to provide desired Fischer-Tropsch products***.

Accordingly, even if Brennan were combined with Ketley and Kolling, the wax product would be passed through a ***high gradient magnetic field*** to remove the small catalyst particles (i.e., particles smaller than 1 micron in size that ordinary filtration is ineffective in removing). Therefore, even if combined Brennan and Ketley and/or Kolling do not disclose or suggest a method of removing contamination from a Fischer-Tropsch derived hydrocarbon stream comprising a) ***filtering*** a Fischer-Tropsch derived hydrocarbon stream ***with a conventional pressure filter*** to remove ***contamination having an average size greater than or equal to about 1 micron*** to produce a filtered hydrocarbon stream; b) passing ***the filtered hydrocarbon stream*** to at least one ***distillation step*** to remove contamination present as soluble species or as ultra-fine particulate from the filtered hydrocarbon stream, the distillation step producing a distillate product stream and a bottoms fraction, wherein the contamination is substantially concentrated in the bottoms fraction; and c) recovering the bottoms fraction from the distillation step, wherein the amount of the bottoms fraction is less than about 35 percent by volume of the filtered hydrocarbon stream.

For at least the above described reasons, withdrawal of the rejection under 35 U.S.C. § 103(a) is respectfully requested.

Conclusion

Without conceding the propriety of the rejections, claim 1 has been amended, as provided above, to even more clearly recite and distinctly claim Applicants' invention and to pursue an early allowance. For the reasons noted above, the art of record does not disclose or suggest the inventive concept of the present invention as defined by the present claims.

In view of the foregoing amendment and remarks, reconsideration of the claims and allowance of the subject application is earnestly solicited. In the event that there are any questions relating to this application, it would be appreciated if the Examiner would

telephone the undersigned attorney concerning such questions so that prosecution of this application may be expedited.

Respectfully submitted,

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Filtration

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13. Batch Pressure Filters

Excluding variable chamber presses, which rely on mechanical squeezing of the cake and are discussed in a separate section, pressure filters may be grouped into two categories, ie, plate-and-frame filter presses, and pressure vessels containing filter elements. The latter group also includes cartridge filters; these are discussed separately. All of the above pressure filters are suited to handling different types of cake. Pressure vessel filters (leaf-type) handle incompressible or slightly compressible cakes. Filter presses handle both compressible and incompressible cakes, especially with the flexibility potential of membranes. Cylindrical element filters, ie, candle filters, are used for clarification applications, using membrane socks (or tubes), precoat and often body-feed, resulting in cakes that are slightly compressible. Cartridge filters are for clarification only, with little if any cake formed.

13.1. Plate-and-Frame Filter Presses

In the conventional plate-and-frame press (Fig. 20), a sequence of perforated square, or rectangular, plates alternating with hollow frames is mounted on suitable supports and pressed together with hydraulic or screw-driven rams. The plates are covered with a filter cloth that also forms the sealing gasket. The slurry is pumped into the frames and the filtrate is drained from the plates.

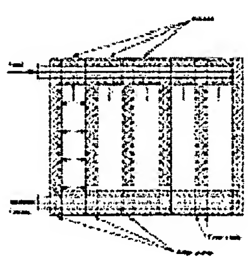

Figure 20.

Principle of plate-and-frame presses.
[Full View]

The drainage surfaces are usually made in the form of raised cylinders, square-shaped pyramids, or parallel grooves in materials such as stainless steel, cast iron, rubber of coated metal, polypropylene, rubber, or wood. Designs are available with every conceivable combination of inlet and outlet location, ie, top feed, center feed, bottom feed, corner feed, bottom external feed, and side feed, with a similar profusion of possible

positions of discharge points. Each combination has particular advantages, depending on whether washing is required and also on the application and nature of the suspension. The discharge may be through a separate cock on each plate, rather than through a common filtrate port and manifold, to allow observation and sampling of the filtrate from each plate. This enables the operator to spot cloth failure and isolate the plate or segregate the cloudy filtrate. The cocks discharge into open channels or enclosed pipe systems fitted with a sight glass.

Both flush plates and recessed plates can be specified. Recessed plates obviate the need for the frames but are tougher on filter cloths due to the strain around the edges. These presses are more suitable for automation because of the difficulty of the automatic removal of residual cake from the frames in a plate-and-frame press.

Plate sizes range from 150 mm to 2.4 m^2, giving filtration areas up to ~800 m^2. The number of chambers varies up to 120 with exceptions to 200.

Plate-and-frame filters are most versatile since their effective area can be varied simply by blanking off some of the plates. Cake holding capacity can be altered by changing the frame thickness or by grouping several frames together. These filters are available in a variety of semiautomated or fully automated versions that feature mechanical leaf-moving devices, cake removal by vibration, or cake removal by pulling the cloth when the press is open, etc. An operator usually must be present, however, because it is not certain that each and every chamber will discharge its cake unaided every time. Should manual intervention be necessary, the operator must be protected by a suitable safety photoelectric device from injury by the plate-moving mechanism, or by the closing mechanism.

Washing performed in filter presses is either simple or thorough washing. In simple washing, the wash liquid is introduced either through the main feed port or through a separate port into each chamber, and the washing is therefore in the same direction as the filtration process that formed the cake. In thorough washing, the wash liquid enters through a separate port, behind the filter cloth on every other plate, thus passing through the whole thickness of the cake in the chamber. Washing is less efficient with recessed chamber presses than with flush plate frame presses, because of poorer distribution of the wash liquid. In either case the amount of wash liquid needed is high.

Filter media for plate-and-frame presses include various cloths, mats, and paper. Paper filter media usually must be provided with a backing cloth for support.

The typical operating pressure of filter presses is 7–15 bar, although some manufacturers offer presses for 30 bar or higher. As the pressure increases during filtration, it forces the plates apart; this may be offset by a pressure compensation facility offered with some large mechanized presses.

Full mechanization of filter presses started in the late 1950s; this was followed by addition of the mechanical expression, ie, cake squeezing, mechanism. Rubber or plastic

membranes are sometimes fitted to compress the cake that is formed by conventional pressure filtration. The membranes normally rest on the plates and have grooves and openings in their surfaces for filtrate collection. They are inflated at the end of the filtration cycle by air, for pressures to ~7 bar, or by water at higher pressures. The membranes should be designed to last up to or in excess of 20,000 cycles. The principal advantages of using mechanical expression of cakes are the additional dewatering usually achieved, the ability to handle thin cakes, and superior cake washing. The main filtration process can be done at lower pressures so that a relatively cheap pump can be used, and the compression by the membrane then goes to higher pressures (107,108).

The automation of filter presses has affected several other advantages and developments. Plate shifting mechanisms have been developed, allowing the cloths to be vibrated; filter cloth washing, on both sides, has been incorporated to counteract clogging and downtimes have been reduced with automation, thus increasing capacities.

The vertical recessed plate automatic press (or tower press) is shown schematically in Figure 21. Unlike the conventional filter press with plates hanging down and linked in a horizontal direction, this filter press has the plates in a horizontal plane placed one upon another. This design offers semicontinuous operation, saving in floor space, and easy cleaning of the cloth, but it allows only the lower face of each chamber to be used for filtration (although the new Hoesch DS tower press allows for double sided filtration (109).

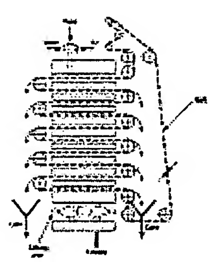

Figure 21.

Vertical automatic filter presses (or tower press). [Full View]

The filter usually has an endless cloth, traveling intermittently between the plates via rollers, to peel off cakes. Unfortunately, if the cloth is damaged anywhere, the whole cloth must be replaced, which is a difficult process. Each time the filter cloth zigzags through the filter, the filtering direction is reversed; this tends to keep the cloth clean. Most of these filters incorporate membranes for mechanical expression, and cakes sometimes stick to the membranes and remain in the chamber after discharge. Because the height of the vertical press makes maintenance difficult, the number of chambers is restricted, usually to 20, with a maximum of 40, with filter areas up to 32 m^2. However, newer designs (eg, Schneider's unit and filtra-Systems' Verti-Press (74,76) offer increased sizes and simpler designs). Some vertical filters (usually called automatic pressure filters or APFs) are available with a separate cloth for each frame. The cloth may be disposable and such filters are designed to operate with or without filter aids (76): and are primarily used in the machine tool coolant and wastewater industries.

The application of filter presses spans virtually all areas of the processing industries due to their versatility. Examples of use include clarification of beer and juices; wastewater and activated sludge filtration in breweries, paper mills, and petrochemical plants; dewatering of fine minerals; lime mud separation; and washing in the sugar industry. Filtration rates are usually from 0.025 to 1 $m^3/m^2/h$. Dry solids handling capacities are <1000 $kg/m^2/h$, with the higher values being more usual with the automatic presses due to their shorter down times.

13.2. Pressure Vessel Filters

The several designs of pressure vessel filters all consist of pressure vessels housing a multitude of leaves or other elements that form the filtration surface and that are mounted either horizontally or vertically. With horizontal leaves most suitable where thorough washing is required, there is no danger of the cake falling off the cloth; with vertical elements, a pressure drop must be maintained across the element to retain the cake. The disadvantage of horizontal leaf types is that one-half the filtration area is lost because the underside of the leaf is not used for filtration because of the danger of the cake falling off. Discharge of the cake also may be more difficult in this case.

The elements or leaves normally consist of a coarse stainless steel mesh over which a fine, often woven metal, mesh or filter cloth is stretched and sealed at the edges. The leaves are in parallel, each connected to a header and, almost without exception, filtration is from the outside in through the medium. These filters are essentially batch operated, and most require the use of a filter aid for precoating to avoid cloudy filtrates and blinding. A separate filtering element is often installed at the bottom of the vessel as a scavenger filter for the filtration of the heel of unfiltered slurry that is still in the vessel at the end of the filtration period. This residual slurry is particularly troublesome with the vertical leaf filters because compressed air cannot be used to complete the filtration of this heel, as the air would preferentially escape through the tops of the leaves as soon as they emerged from the suspension. During the scavenge filtration the main leaves are usually isolated so that compressed air is not lost through them.

13.2.1. Cylindrical Element Filters

These filters, often referred to as candle filters, have cylindrical elements or sleeves mounted vertically and suspended from a header sheet, which divides the filter vessel into two separate compartments (Fig. 22). The filtration takes place on the outside of the sleeves, but in some designs, filtration takes place on the inside generally used for semidry cake discharge (74). The inlet is usually in the bottom section of the vessel and the filtrate outlet in the top section above the header (or tube) sheet.

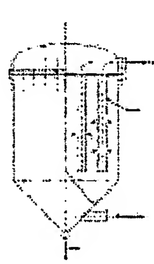

Figure 22.

A cylindrical element (candle) pressure filter.
[Full View]

The tubes generally measure from 25 to 75 mm in diameter, and up to 2.5 m in length. Made from metal or cloth-covered metal or thin membrane-type socks over various tube designs, they provide filtration areas up to 100 m^2. Alternatively, the tubes can be made of stoneware, plastics, sintered metal, or ceramics. The elements may be deliberately made flexible, and tank diameters up to 1.5 m are available. Cake removal is performed by scraping with hydraulically operated scraper rings, by vibration, by turbulent flow bumping, or by backwashing. The mechanical strength of the tubular element makes it ideal for cleaning by the sudden application of reverse pressure. Physical expansion or flexing of the tubular elements on application of the reverse flow aids cake discharge. These filters find wider use where cake washing is not required.

The advantage of candle filters is that as the cake grows on the outside of the tubular elements the filtration area increases and the thickness of a given volume of cake is therefore less than it would be on a flat element. This is of importance where a thick cake is being formed; the rate of increase in the pressure drop is less with tubular elements.

A new type of candle filter (Amafilter's Cricketfilter, Holland) has been introduced that have flattened candles that reportedly permit more elements per unit volume and allow for better backwashing or backpulsing (110).

An even more unique candle filter (DrM's Fundabae, Switzerland) uses multiple small tubes for enhanced cake removal from their usual woven cloth socks (111). Both of these designs can provide for dry cake discharge.

The pressure filter with tubular elements has also been used as a thickener, when the cake, backwashed by intermittent reverse flow, is redispersed by an agitator at the bottom of the vessel and discharged continuously as a slurry. In some cases, the filter cake builds up to a critical thickness and then falls away without blowback.

13.2.2. Vertical Vessel, Vertical Leaf Filters

These are the cheapest of the pressure leaf filters and have the lowest volume/area ratio (Fig. 23). Their filtration areas are limited to < 80 m^2. Large bottom outlets, fitted with rapid-opening doors, are used for dry cake discharge, and smaller openings are used for slurry discharge. Wet discharge may be promoted by spray pipes, vibrators, reverse flow, bubble rings, scrapers, etc, while dry discharge is usually caused by vibration. As with all vertical leaf filters, these are not suited for cake washing.

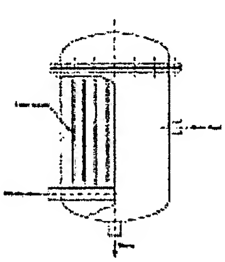

Figure 23.

Vertical vessel, vertical leaf filter.
[Full View]

In the Scheibler filter, the filter leaves take the form of bags, each suspended in a rectangular pressure vessel from a horizontal tube that acts as the filtrate outlet. The sides of the bag are prevented from meeting by looped chains that are attached at the top of the loop to the horizontal tube and hang downward. With this method of separating the cloth surfaces by chains, the bags can be wide enough to hang in pleats and the filtering area can thus be as much as three times the area of the frames inside the bags. Filtration areas up to 250 m^2 are available with applications being mostly in the chemical industry. An improved version of this Scheibler is now offered by Larox.

13.2.3. Horizontal Vessel, Vertical Leaf Filters

In a cylindrical vessel with a horizontal axis (Fig. 24), the vertical leaves can be arranged either laterally or longitudinally. The latter, less common, arrangement may be designed as the vertical vessel, vertical leaf filters but mounted horizontally. Its design is suitable for smaller duties and the leaves can be withdrawn individually through the opening end of the vessel.

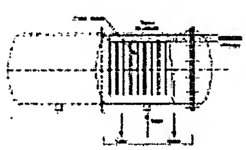

Figure 24.

Horizontal vessel, vertical leaf filter.
[Full View]

Filtration areas up to 120 m^2 are available with the Kelly leaf filter, another longitudinal arrangement and probably the earliest pressure leaf filter. It has been used for the filtration of very viscous liquids such as glycerol and concentrated sugar solutions. The height of the leaves varies according to the space available at their location in the vessel. The leaves are attached to the removable circular front cover, with each leaf having an outlet connection through this cover. The leaves, together with the cover and outlet pipes, are attached to a carriage that can be run into and out of the shell to facilitate cake discharge outside the vessel by air blowback or rapping. This arrangement requires a considerable amount of floor space and to minimize this drawback the filters are often constructed in pairs on a single runway, with their opening ends facing each other. Thus each filter can be opened in turn into the common space between them.

Horizontal vessel filters that have the vertical leaves arranged in a plane perpendicular to the axis of symmetry of the vessel, ie, laterally, have the greatest use because they provide easy access to the leaves. Most of these designs open in a way similar to the Kelly filter. Some designs move the shell rather than the leaf assembly so that the filtrate pipe can remain permanently connected; withdrawal of one leaf or a bundle of leaves at a time is possible. The leaves may be rectangular, circular, or of some other shape, and may be designed to rotate during cake discharge. Sluicing by sprays is used for wet discharge, with or without rotation of the leaves. If the leaves are designed for rotation, they are invariably circular and mounted on a central hollow shaft that serve as the filtrate outlet. Dry cake discharge may be carried out with rotating leaves by application of a

scraper blade. If this is to be done without opening the vessel, then the bottom of the vessel must be shaped as a hopper, with a screw conveyor if necessary.

The Vallez filter, originally developed in the United States for the sugar industry, rotates the leaves at ~1 rpm during the filtration operation to keep the solids in suspension and achieve a more uniform cake.

The Sweetland filter, a significant departure from the standard end-opening design, has the cylindrical shell split in a horizontal plane into two parts, where the bottom one-half can be swung open for cake discharge. The upper one-half is rigidly supported and both the feed and the filtrate piping are fixed to it. The lower part is hinged to the upper along one side and is counterbalanced for easy opening. Cake discharge is either by sluicing or by dropping, assisted by some scraping. If much scraping is needed, there is not much advantage in using this type of filter. Because the leaves are stationary, the cake deposited on them may be uneven, with greater mass of cake at the bottom of the leaves.

Generally, the horizontal vessel, vertical filters with leaves arranged laterally can be designed up to filtration areas of 300 m^2. Cake washing is possible but must be carried out with caution since there is a danger of the cake falling off.

Horizontal vessel filters with vertical rotating elements have been under rapid development with the aim of making truly continuous pressure filters, particularly for the filtration of fine coal.

13.2.4. Vertical Vessel, Horizontal Leaf Filters

These filters, like all horizontal leaf filters, are advantageous where the flow is intermittent or where thorough cake washing is required. Filtration areas are limited to ~45 m^2.

The pressure versions of the nutsche filter, which falls into this category, are either simple pressurized filter boxes or more sophisticated agitated nutsches, much the same in design as the enclosed agitated vacuum filters described earlier. These are extremely versatile, batch-operated filters, used in many industries, eg, agrochemistry, pharmaceuticals, or dyestuff and foodstuff production.

An obvious method of increasing the filtration area in the vessel is to stack several plates on top of each other; the plates are operated in parallel. One design, known as the plate filter, uses circular plates and a stack that can be removed as one assembly. This allows the stack to be replaced after the filtration period with a clean stack, and the filter can be put back into operation quickly. The filter consists of dimpled plates supporting perforated plates on which filter cloth or paper is placed. The space between the dimpled plates and the cloth is connected to the filtrate outlet, which is either into the hollow shaft or into the vessel, the other being used for the feed. When the feed is into the vessel, a scavenger plate may have to be fitted because the vessel will be full of unfiltered slurry at the end of the filtration period. This type of filter is available with filtration areas up to 25 m^2 and cakes up to 50 mm thick.

Centrifugal discharge filters form another group in this category. As the name suggests, the cake discharge is accomplished by rotating the stack of plates around the hollow shaft. The cake slides off the plates due to the centrifugal action; sometimes it is necessary to supplement this by sluicing with a suitable liquid, in which case the discharge is wet. The filtrate leaves through the hollow shaft. These filters lend themselves to automation and, as opposed to manually operated leaf filters, they can be operated with short cycle times and very short downtimes, which is economical. Many different designs are available, with various ways of driving the shaft and locations of the electric motor as well as other varying constructional details. Sizes vary up to 65 m^2.

Another available design allows discharge of the cake by vibration of the circular plates, which are slightly conical, sloping downward toward the outside of the plates. This design allows higher pressures to be used as there are no rotating seals necessary.

13.2.5. Horizontal Vessel, Horizontal Leaf Filters

These filters consist of a horizontal cylindrical vessel with an opening at one end (Fig. 25). A stack of rectangular horizontal trays is mounted inside the vessel; the trays can usually be withdrawn for cake discharge, either individually or in the whole assembly. The latter case requires a suitable carriage. One alternative design allows the tray assembly to be rotated through 90° so that the cake can fall off into the bottom part, designed in the shape of a hopper and fitted with a screw conveyor.

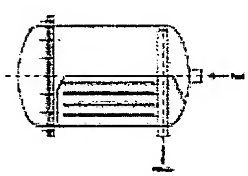

Figure 25.

Horizontal vessel, horizontal leaf filter.
[Full View]

The trays may be fitted with rims; this is particularly useful for flooding the trays in washing operations. Scavenger leaves are often used. Filtration areas up to 50 m^2 are available. Like all horizontal leaf filters, horizontal vessel, horizontal leaf filters are particularly suitable when thorough washing is needed.

13.3. Cartridge Filters

Cartridge filters use easily replaceable, tubular cartridges made of paper, sintered metal, woven cloth, needle felts, activated carbon, or various membranes of pore size down to ~0.1 μm. Filtration normally takes place in the direction radially inward, through the outer face of the element, into the hollow core (Fig. 26). Cartridge filtration is limited to liquid polishing or clarification, ie, removing very small amounts of solids, in order to keep the frequency of cartridge replacements down. Typically, suspensions of <0.01% vol concentration of solids can be treated with cartridge filters, and such filters are favored in small-scale manufacturing applications.

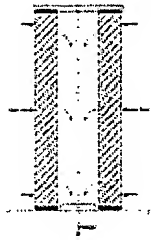

Figure 26.

The principle of cartridge filters.
[Full View]

Cartridge filters are either depth or surface type, according to where most of the solids separate; the precise demarcation line is difficult to assess. The most common depth cartridge is the yarn-wound type that has a yarn wound around a center core in such a way that the openings closet to the core are smaller than those on the outside. The aim is to achieve depth filtration, which increases the solids-holding capacity of the cartridge. The yarn may be made of any fibrous material, ranging from cotton or glass fiber to the many synthetic fibers such as polypropylene, polyester, nylon, or Teflon. The spun staple fibers are brushed to raise the nap and this makes the filter medium. The cores are made from polypropylene, phenolic resin, stainless steel, or other metals or alloys. The nominal mm rating of this type of cartridge varies from 0.5 to 100 μm, but are generally only ~70% efficient. On the other hand, they are the most economical.

Cartridges for higher viscosity liquids are often made of long, loose fibers, again either natural or synthetic, impregnated with phenolic resin. Such bonded cartridges are usually formed into the shape of a thick tube by a filtration technique and do not require a core because they are self-supporting. The porosity of the medium can be graded during the formation process, again to increase the solids-holding capacity. Bonded cartridges are available in somewhat coarser ratings from 10 to 75 μm.

Depth-type cartridges cannot be cleaned but have high solids-holding capacity, and are cheap and robust. Considerable standardization of the cartridge size throughout industry, ~25, 50, 75, and 100 cm long, 6.3–7.0-cm overall diameter, and 2.5-cm internal diameter, allows testing of different cartridge makes and types in the same cartridge housing.

A common surface cartridge is the pleated paper construction type, which allows larger filtration areas to be packed into a small space. Oil filters in the automobile industry are of this type. The paper is impregnated, for strength, with epoxy or polyurethane resin. Any other medium in sheet form, similar to cellulose paper, such as polypropylene, glass, or a variety of nonwovens, may be used.

The nominal rating ranges from 0.2 to 50 μm. Pleating in the radial direction is usual, but some cartridges have axial pleating, or, in an effort to pack as much filtration surface into a given space as possible, have hollow disks of lenticular shape; up to 3 m^2 of surface in one cartridge is possible. The solids-holding capacity of pleated paper surface cartridges is low but some applications allow the prolonged buildup of solids on the surface, until the pleats are completely filled up.

Another type of cartridge is the edge filter that contains a number of thin disks mounted on a central core and compressed together. The disks are usually made of metal although paper or plastics are used. Filtration takes place on the surface of the cylinder, with the particles unable to pass between the disks. The principal advantage of the edge-type filter is that it is cleanable. This is done by reverse flow, ultrasonics, oscillation, or by scraping the outside surface of the cylinder with a mechanical scraper. Edge filters made from paper disks have been known to retain particles as fine as 1 μm but the metal variety retains solids >50 μm or so. Other designs of cartridges use active carbon, Fuller's earth, sintered metal, or other specialized media.

The most important characteristics of cartridge filters are the filter rating, ie, the largest particle (~98% nominal and 99.98% absolute retention cut size) that passes through the filter; the relationship between the pressure drop and solids-holding capacity; and the maximum allowable pressure drop beyond which the cartridge fails structurally. Both the retention and the solids-holding capacity depend on filtration velocity and this must be considered when testing cartridges. Thermal or shock stresses can lead to cracking of cartridges, with the subsequent loss of filtrate clarity. Standardized tests are now available to test and validate most cartridges.

The housings of cartridge filters are simple pressure vessels designed for one cartridge, or a number of cartridges in parallel, in multielement filters. Some housings are designed to withstand pressures up to 300 bar. Proper sealing of the elements is a necessary prerequisite of their efficient use. Frequent replacement of cartridges should be facilitated by quick-opening clamping fittings.

Cartridge filters are used to clean power fluids, lubrication oils, DI water, wines, fruit juices, or pharmaceutical liquids. They are also used to protect other equipment, eg, in control systems or automatic valves. Low capital and installation costs, low maintenance costs, simplicity, and compactness are the main advantages of cartridge filters. Running costs are high, especially when disposable cartridges are used. It is most important, therefore, that a full economical analysis, based on reliable cartridge replacement frequency, is carried out before adopting a cartridge filtration system; the low cost of the basic hardware may be deceptive.

13.4. Mechanical Batch Compression Filters

In conventional cake filtration the liquid is expelled from the slurry by fluid pressure in a fixed-volume filtration chamber; in mechanical compression this is achieved by reduction of the volume of the retaining chamber. This compression of either a slurry or a cake, which might have been formed by conventional filtration, offers advantages to industries handling a variety of different materials. Such materials include highly compressible, sponge-like solids; very fine particles such as clays; fibrous pulps; gelatinous mixtures like starch residues or some pharmaceuticals; and flocculated wastewater sludges.

The compressibility of filter cakes is a nuisance from the point of view of the filtration theory. In practice, it means that with increasing pressure cakes become more compact and therefore drier and more difficult to filter. The resistance to flow increases due to reduced porosities, however, and, with some materials, eg, paper mill effluents and

municipal wastewater sludges; higher pressures do not necessarily give increased flow rates. In cakes undergoing conventional pressure filtration, the bottom layers closest to the medium are subjected to the highest compression forces whereas the top layers are subjected only to light hydraulic forces and are not compacted so tightly. If a mechanical force is applied to the top of the filter cake, the distribution of pressure through the cake is more uniform. Cakes drier than those formed by using high pumping pressures of the feed suspension can thus be achieved.

Since 1980 (75,107,108), a number of new filters have appeared on the market, utilizing some form of mechanical compression of the filter cake, either after a conventional pressure filtration process or as a substitute for it. In most designs, the compression is achieved by inflating a diaphragm that presses the slurry or the freshly formed filter cake toward the medium, thus squeezing an additional amount of liquid out of the cake.

Other designs squeeze the cake between two permeable belts or between a screw conveyor of diminishing diameter, or pitch, and its permeable enclosure. The available filters that use mechanical compression can be classified into four principal categories, ie, membrane plate presses, tube presses, belt presses, and screw presses.

Membrane plate and tube presses are dealt with here; belt and screw presses are included in the discussion of continuous pressure filters.

The advantages of using mechanical compression with compressible cakes include increased solid content of the cakes, leading to reduced energy requirements if thermal drying has to follow, or to better handling properties; improved washing efficiencies; increased filtration rates; and easier or automatic cake discharge. Invariably, however, the capital cost of such filters is higher than for conventional pressure filters. Whenever a membrane is used for the compression, however, this increases the capital cost and thus, variable chamber filters tend to be more expensive than conventional filters in the same category.

13.4.1. Membrane Plate Presses

Membrane presses are closely related to conventional plate and frame presses. They consist of a recessed plate press in which the plates are covered with an inflatable diaphragm that has a drainage pattern molded into its outside surface. The filter cloth is placed over the diaphragm (Fig. 27). During the first stage of filling the filter chambers with the slurry and conventional pressure filtration, the membrane is pushed against the plate body. When the chambers are relatively full of cake, the feed is terminated and the membranes are inflated by pumping compressed air or hydraulic fluid in between the membranes and the plates; the cake in the chamber is compacted as the membranes expand. Washing of the cake may follow and can be carried out more effectively than in a normal press because the cake is compacted to a more uniform density by squeezing. The resulting advantage is in the reduction of the washing time and washwater requirements. The squeeze pressures vary from 6 to 30 bar. Additional reductions of up to 25% in the moisture content over that obtained with conventional filter presses can be achieved. The membranes are usually made of rubber compounds, polypropylene or (PVDF), which are resistant to solvents.

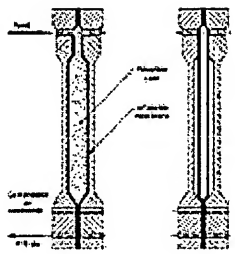

Figure 27.

Membrane plate press, ie, recessed plate with variable chamber press.
[Full View]

Another advantage of the membrane plate is its flexibility to cake thickness, ie, thinner cakes can be easily handled with increased cake dryness. Cake release characteristics are also improved by deflation of the membranes prior to cake discharge. Alternating arrangements, in which the membrane plates and the normal recessed plates alternate, have been used to reduce cost.

The plate press filter replaces the pneumatically operated membranes with flexible seals and compression by a hydraulically powered ram. The cake is formed in the chambers between the hollow circular frames carrying the filter medium and the flat rectangular discharge plates. The frames are sealed against the discharge plates by rubber rim seals which form the filtration chambers. As the rim seals are compressed by the hydraulic ram, the cake inside is squeezed. The filter is then opened, the cake adheres to the discharge plates and, as the plates are lowered and raised again, the cake is removed by scrapers. The process is fully automated and the filtration areas available go up to 20 m^2. No washing of the cake is possible.

The OMD leaf filter (Stella Meta Filters and Industrial Filter) is a vertical leaf filter with a rubber diaphragm suspended between the leaves. The cake that forms on the leaves eventually reaches the diaphragm at which point pump pressure is used to inflate the diaphragm and compress the cake. The cake discharge is by vibration.

A variation of the same principle is the DDS-vacuum pressure filter, which has a number of small disks mounted on a shaft that rotates discontinuously. The cake is formed on both sides of the disks when they are at the bottom position, dipped into the slurry. When the disks come out of the slurry and reach the top position, hydraulically driven pistons squeeze the cake and the extra liquid then drains from both sides of the cake. The cake is removed by blowback with compressed air.

Cake compression by flexible membranes is also used in the new automated vertical presses that use one or two endless cloth belts, indexing between plates [ie, Hoesch, Larox tower presses and Filtra-Systems' Verti-Press (74)].

Filtration and compression take place with the press closed and the belt stationary; the press is then opened to allow movement of the belt for cake discharge over a discharge roller of a small diameter. This allows washing of the belt on both sides (Fig. 21). Cycle times are short, typically between 10 and 30 min, and the operation is fully automated.

Sizes up to 32 m^2 are available and the maximum cake thickness is 40 mm.

Washing and dewatering by air displacement of cakes are possible. Applications are in the treatment of minerals, in the sugar industry, and in the treatment of municipal sewage sludge and fillers like talc, clay, calcium carbonate, etc.

The versatility of these batch membrane presses has been further enhanced in the past few years by combination with *in situ* heating and vacuum drying so the entire dewatering–drying process is conducted in one piece of equipment. Some municipal sewage sludges are dried via this process (112). Four vendors are actively pursuing this technology: JWI (USFilter), DryVac, Bertrams, and Eurofilter.

13.4.2. Cylindrical Presses

Another group of filters that utilize the variable chamber principle are those with a cylindrical filter surface. There are two designs in this category, both of which originate from the United Kingdom.

The VC filter (Fig. 28) consists of two concentric hollow cylinders mounted horizontally on a central shaft. The inner cylinder is perforated and carries the filter cloth, the outer cylinder is lined on the inside with an inflatable diaphragm. The slurry enters into the annulus between the cylinders and conventional pressure filtration takes place, with the cake forming on the outer surface of the inner cylinder. The filtration can be stopped at any cake thickness or resistance, as required by the economics of the process, and hydraulic pressure is then applied to the diaphragm that compresses the cake.

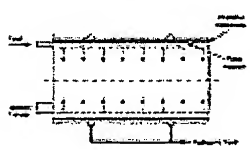

Figure 28.

Principle of the VC filter.
[Full View]

As with other filters of this type, washing can be carried out by deflation of the diaphragm and introduction of washwater into the annulus. Reinflation of the membrane then forces the wash liquor through the cake, thus displacing the mother liquor. At the end of the process, the inner cylinder is withdrawn from the outer shell and the cake is either discharged manually or blown off with compressed air. Sizes available range from small, mobile test units of 0.4-m^2 area to large, fully automated machines with 6.1-m^2 filtration area. Choice of two alternative core sizes is offered, giving annuli of 6 or 2.8 cm available for the cake. The hydraulic pressure for operating the membrane goes up to 14 bar. Although originally developed for filtration of dyestuffs, the VC filter has been successfully used for the filtration of gypsum, china clay, cement, industrial effluents, metal oxides, coal washings, nuclear waste, and other slurries.

The ECLP tube press is smaller in diameter and, unlike the VC filter, is operated in a vertical position. It uses compression only, both for the filtration and for squeezing the cake. The space between the cylindrical rubber membrane and the cloth tube is first filled

with the slurry and the hydraulically operated membrane is used to drive the liquid through the cloth. It follows, therefore, that this filter is suitable for higher solids concentrations, usually in excess of 10% by weight, in order to obtain the minimum cake thickness necessary for efficient cake discharge of ~4 mm. At the end of the process, the central core is lowered by ~300 mm and the cake is removed by a blast of compressed air from the inside. The hydraulic operating pressures are higher than the VC filter at ~150 bar but the single tube area is only ~1.3 m^2. Multiple tube assemblies are used to treat larger flows. Cake washing is possible but with some solids there is a danger of the cake falling off the inner core while the annulus is being filled with water.

The ECLP tube press was originally developed for the filtration of china clay but has been used with many other slurries such as those in mining, TiO_2, cement, sewage sludge, etc. The typical cycle time is ~4 min or more.